SEIS - Space Environment Information System* for Mission Control Purposes

(http://www.uninova.pt/ca3/en/project_SEIS.htm)

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Context

Although the Space Weather has been directly and indirectly identified as the source for a large percentage of S/C abnormal behaviours (through high radiation levels emissions, solar flares and magnetically induced fields), little can be done by FCT operators up until now to minimize the impact of S/C faults.

One of the most common observed faults in S/C, are SEUs (Single Event Upsets), which are mainly caused by S/C exposure to excessive amounts of radiation.

These SEUs occur when a single ionising radiation event (direct ionisations/proton-induced nuclear reactions) produces a burst of hole-electron pair in a digital circuit, large enough to cause the circuit to change the state, preventing the execution of nominal operations for a particular unit or resulting in permanent damage of the unit itself.

One of the responsibilities of the Flight Control Teams is to try to optimise the operations on the S/C during known occurrences of high radiation levels, in order to prolong the expected operation usage time of the instruments.

The most common risk-avoidance procedure consists in reaching a so-called 'safe configuration' for the units (e.g. switching off the instruments high-voltages/biases off), or (when available) protecting sensible instruments by using some kind of active shielding (filter/anticoincidence system).

The main problem resides in the fact that, most of the times, due to the preventive actions, Flight Control operators cannot extract new readings from the sensors (e.g. radiation sensors from the XMM satellite), but only from supplementary radiation monitoring instruments, being therefore unable to accurately identify or even determine whether safe conditions for the reconfigurations of the units have been reached or not.

Moreover, because Space Weather event data is not being correlated with telemetry readings from the S/C sensors, whenever a telemetry reading surpasses a fixed threshold limit (generating an out of limits condition/notification of an on board anomaly), Flight Control operators will react immediately, initiating the risk-avoidance procedures reported in the FOP (Flight Operations Plan) – the main operational document for S/C operations.

These processes usually assume the worst-case possible scenario (where some Space Weather events, like radiation belt crossing, cause S/C exposure to extreme levels of radiation during a pre-defined time-window/attitude range) and normally, require that instruments (high voltages/biases/filters) are switched-off during an even within a larger time-window than the pre-defined one. By using a larger time window, FCT operators hope that when the reconfiguration procedure is initiated (instruments – high voltages/biases/filters - are switched-on again), the radiation levels have decreased to acceptable limits.

Although, correlation between a high-level radiation reading and a possible upcoming extreme radiation event can be done, most of the times corresponds to punctual radiation measurements, lasting for very short periods of time.

* This project is integrated on the Space Weather Pilot Programme as an external funded activity.

As caution, FCT operators initiate risk-avoidance procedures, as there is no way to differentiate between a punctual high reading and an upcoming radiation event caused by Space Weather. This results in poor instrument time optimisation, since to reduce the chance of serious anomalies, instruments are being switched-off many times and during larger periods than they could/should be really off, adding thermal/electric stress for the units.

The most common model for trapped electron and proton (AP-8 and AE-8) are static models that do not take into account the dynamics of Magnetosphere. Last missions demonstrated that trapped radiation environment is more complex than static environment. Spatial and especially temporal variation are more important (a new generation of models are now becoming available but they are still limited in spatial/temporal coverage and a valid global radiation model is still missing).

Improved knowledge of the Space Weather factors and better modelling of the space environment would increase the productivity of the units, by allowing FCT operators to take appropriate actions (e.g. optimisation of the observation windows) sooner.

Goal

UNINOVA has been increasing its experience, with past and on-going projects at ESOC, in radiation monitoring and prediction and the usage of this information in the assessment of Solar cells degradation (details available at http://www.gtd.es/fuzzy). This, along with our combined expertise in Artificial Intelligence, Data Mining, Machine learning, Fuzzy Logic and Decision Support Systems (mainly data warehousing), are behind this identified opportunity (see (Ribeiro, Pires et al. 2002) for an overview of these technologies and possible future applications).

Our experience of current practices of mission operations at ESOC is that operators can benefit from systems that deliver relevant information and knowledge, usually not integrated in the mission control environment. Space weather data is definitely included. In addition, space weather data is not used in standard documented mission control processes:

- This perception is also confirmed by the assessment of current practices performed in the feasibility studies of (see (Horne 2000) – page 33). Operators cannot reliably identify space weather as a cause of problems since they do not have enough expertise in space physics and information about the spacecraft environment.
- The **identified user need** is to supplement the flight control team with **space environmental information** - past, current and forecast - already translated into spacecraft operational impact assessment and, in combination with spacecraft telemetry data, into suggested preventive or corrective operational procedure(s) (as defined in the S/C Flight Operation Plan) for implementation.
- With the opportunity implicit in the previous statements in mind, UNINOVA has envisioned a solution which consists of:

  a) Collecting historical and real-time space weather data coming from whatever sources are deemed relevant (opportunistic usage) for a specific operations context and integrate that data with the satellite telemetry and orbit.
  b) Transform the Space Weather raw data into information and knowledge at higher levels of abstraction.
  c) Develop a prototype system capable of delivering a set of space weather services designed for mission control purposes directly in the control room.

The **user benefits** include **increased awareness of space weather cause & effect** relationships; vis-à-vis on-board spacecraft health status; **improved productivity and safety levels** of satellite operations versus space weather environmental phenomena; increased science return and extended life time.

Technology

The SEIS prototype to be developed, will be used by the INTEGRAL and ENVISAT mission flight control operators (FCT teams) and integrates several key technologies:

- Data Warehousing (decision support oriented database)
- MOLAP Analysis (data exploration and correlation analysis reporting)
- Artificial Neural Networks (general time-series forecasting)
- Knowledge Based System (capture of domain experts' knowledge)

While some of these technologies have already proven themselves on other domains of application (such as Data Warehousing and MOLAP Analysis – business domain), the latter (ANN and KBS) represent two blocks to be prototyped under the scope of the project.

Overview

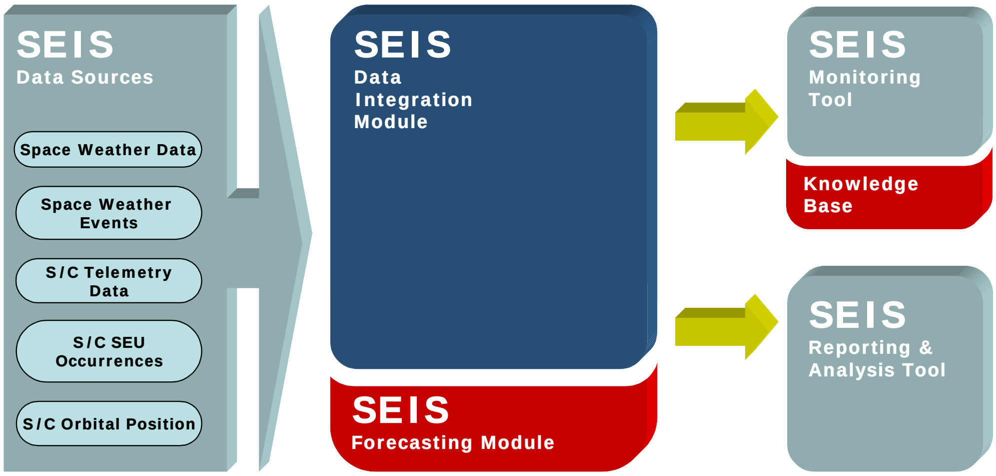

Figure 1 – Basic components of the SEIS architecture.

The SEIS system will integrate data from different heterogeneous Space Weather data sources (NOAA, SOHO), Space Craft telemetry (XMM, ENVISAT, INTEGRAL), forecasting data and available Single Event Upset (SEU) databases' data (from several missions). will be loaded into a **Data Warehouse**, which is the key storage block of the whole system.

The **Knowledge Based System** engine feeds on this data (frequently refreshed) and infers possible alarms and explanations while providing nowcasting capabilities, shown on a **Monitoring Tool**.

Besides loading Space Weather forecasts, the SEIS system also incorporates a **Model Manager** component capable of building prediction models based on neural networks and generating predictions.

Although the majority of the tasks will be automatically performed, to ensure its usability, this architecture requires the presence of:

- Domain expert capable of managing the represented knowledge on the Knowledge Based System
- Database administrator, responsible for house-keeping activities on the Data Warehouse and MOLAP databases
- Data mining expert, capable of building and maintaining coherent prediction models

Results

The first development phase of the SEIS system has just started, however some goals have already been established:

- Allow Space Craft Flight Control teams to directly correlate Space Weather events with single event upset occurrences through data exploration and analysis
- Provide short term forecasts of environmental factors most relevant to operational purposes
- Provide Space Craft controllers with nowcasting of Space Weather events, possible Single Event Upset (SEU) alarms and their direct relationship with Space Craft mission data

Acronyms and Abbreviations

Acronym / Abbreviation	Designation
ANN	Artificial Neuronal Networks
ETL	Extract-Transform-Load Data Process
FCT	Flight Control Team
KBS	Knowledge Based System
MOLAP	Multidimensional Online Analytical Processing
NOAA	National Oceanic & Atmospheric Administration
S/C	Space Craft
SEIS	Space Environment Information System
SEU	Single Event Upset

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